

An Autonomous Power Supply System Based on a Rotor-Blade Engine with External Heat Application and an AC Electronic Motor with Permanent Magnets

A. E. Kozyaruk and A. A. Khitrov

Received November 21, 2011

Abstract—The possibility of using an AC electronic motor with permanent magnets in an autonomous low-power supply system with a modified Stirling engine is considered. Possible structures, including experimental facilities, are presented.

Keywords: autonomous power supply source, AC electronic motor with external heat supply, thyatron motor with permanent magnets, starter–generator.

DOI: 10.3103/S1068371211120066

Introducing nontraditional renewable energy sources (RESS) and autonomous electricity supply systems (AESSs) using gas fuel is a topical problem at present. This is because of the need to provide power security, enhance the use efficiency of fuel–energy resources, and reduce environmental impact. If in 1980 the share of electric energy produced by RESS amounted to only 1%; by 2020, according to data of the American Society of Electrical Engineers data, it will reach 13%; and, by 2060, 33% [1]. It is planned in the European Union to enlarge the share of RES use for production of thermal and electric energy from 6% (1996) up to 12% (2011).

On April 1, 2002, a law came into effect in Germany for supporting of renovation and development programs of combined production (cogeneration) of electric energy and heat (KWK facilities), and the law on the priority of RES EEG in 2004 stipulated a the importance of connection to the public electricity supply network of facilities for production of electric energy from renewable sources and mine gas (mine methane).

According to experts, the extant resources of coal methane do not exceed those of natural gas, the amounts of which exceed considerably oil resources in investigated territories [2].

Before 2008, coal methane was simply burned on torch devices, since, in Russia, technologies for using coal methane were virtually absent. This fuel may hold promise for production of heat and electrical energy in Stirling power facilities [3]. Physically, a Stirling machine represents a combination of a compressor, an expander, and heat-exchange devices—a heater, regenerator, and cooler forming the main duct with working gas, which moves between cold and hot sections. Heating in the Stirling engine is provided by

burning of any fuel. Stirling engines belong to the class of engines with external heat supply (EEHS).

A modernized Stirling engine version with replacement of the piston system on a rotary-blade assembly—a rotary-blade engine with external heat supply (RBEEHS) [4]—has been elaborated and patented at the Pskov State Polytechnic Institute (PPI). The prototype of this engine using 1.5 kW of power designed at the PPI may be used for creation of an AESS.

Figure 1 shows the general structure of electric energy “supply” to the consumer. Designing an AESS on the basis of an RBEEHS requires development and studying of the operating modes of a starter–generator device for such facilities (a mechanical–electrical converter).

The AESS may be built on the basis of asynchronous and synchronous AC generators, cascade schemes with asynchronized synchronous generators, DC generators, et al. [5].

Synchronous generators with excitation from permanent magnets (SGPMs) have a number of advantages, such as reliability, design and service simplicity, and absence of a need for an excitation coil. Such generators are used in many types of transport facilities and other roles and seem promising.

Thus, one optimal solution is application of an SGPM generator device.

Wide use of new forms of electric machines with permanent magnets is justified for the following reasons:

- a tendency toward reduction of the cost of rare-earth permanent magnets with high specific energy;
- accessibility of reliable semiconductor rectifiers and inverters;

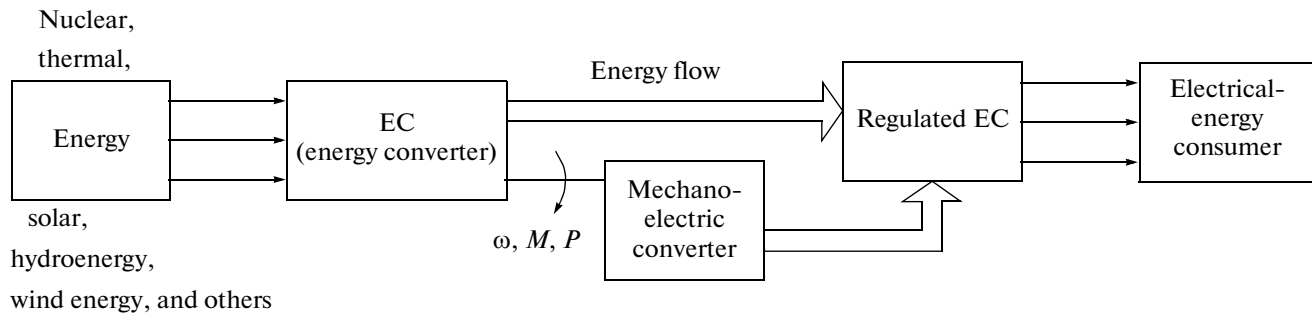


Fig. 1. Generalized scheme of electrical-energy delivery to a consumer.

—the appearance of rapid-operation industrial microcontrollers allowing effective control of AC electronic motors on a real-time scale; and

—the appearance of low-cost accumulator batteries with high specific capacity up to 160 Wh/kg.

At present, there exists serial production of several Stirling engines modifications with power from 10 to 100 kW (for example, the SOLO Stirling 161 CHP) [3].

Low-power facilities from 3 to 10 kW based on RBEEHSs may be used in automation systems, communication, and cathode protection of gas-main pipelines, as well as for provision of electric energy and heat for gas producers and other objects. At present, such energy installations are being designed.

Practical experience in the use of AESSs based on petroleum and diesel electric stations shows that low-power installations may be effective in the farming industry and for individual power supply of individual homes and groups of buildings or a small town as a whole.

From the engineering point of view, the possibilities of using standard AC electronic motors with permanent magnets (EMPMs) as starter-generator AESS devices (DVU2M, 5DVM, et al.) have been investigated rather little. Calculation techniques, modeling, and design of such electric machines have also been elaborated insufficiently.

Existing design techniques of SGPMs are concentrated mainly on high-speed machines that are used in aircraft as generators, consisting of electric-engine transducers and autonomous power supplies driven by air or gas turbines. Moreover, the rotor's rotation fre-

quencies of such SGPMs lie in the range from 3000 to several hundreds of turns per minute.

The output shaft rotation frequency of the RBEEHS designed at the PPI may be regulated in the range of 400–1500 rpm.

A low-speed SGPM designed for use in wind-power facilities and microhydroelectric stations may be used for RBEEHSs (the parameters of some SGPMs are presented in the table) [6].

The nominal voltages and currents for SGPMs of GEN type shown in the table correspond to an active load after a three-phase diode rectifier. However, the cost of such machines is rather high, so that their use in the starter regime for efficient RBEEHS start-up is problematic.

Consider now a possible use of a special electromechanical converter or common industrial EMPM as a starter-generator for an RBEEHS.

The possible use of a special EMPM the rotor of which features rare-earth magnets of Nd–Fe–B type and the stator of which exhibits two three-phase windings, one of which is a generator on nominal current up to 100 A and the other of which is also a generator on nominal current up to 10 A, is illustrated in Fig. 2. Possible manufacturers of separate AESS components are specified here also.

RBEEHS start-up is triggered by a storage battery with use of an inverter, for example, the MUVDM-100 (Electrum AV Corp., Orel).

After a nominal rotation frequency is reached, the starter winding (1A, 1B, 1C) is switched off and the generator one (2A, 2B, 2C) is switched on. Electric

Comparative data of some SGPMs

SGPM type	Nominal rotation frequency, rpm	Nominal power, kW	Nominal voltage, V	Nominal current, A	Mass, kg
GEN-500-6	500	6	130	46	31
GEN-300-3.5	300	3.5	90	40	31
GEN-300-2	300	2	60	33	20
VG-5/114-300	300	5	114	—	95

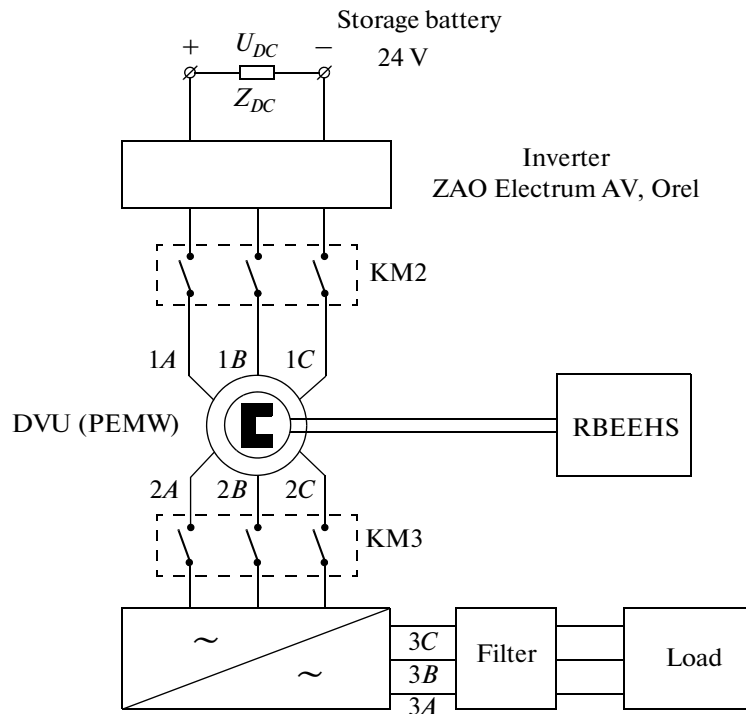


Fig. 2. The possibility of using a special EMPM with rare-earth permanent magnets on the rotor and two three-phase windings on the stator.

energy is fed to the consumers through an AFE module (recuperative block) and filter. Thus, one can identify the following modules in the AESS:

- an RBEEHS with a fuel energy conversion system;
- a starter-generator based on a special electric machine;
- a recuperative block (active front end (AFE)); and
- a control system of the engineering process made, for example, with fuzzy-logic elements.

The unit-type AESS organization allows its assembly from separate modules:

- a storage battery (SB) of 12, 24, or 48 V: a maintenance-free waterproof battery with necessary supply in A h;
- an inverter of the starter and generator;
- a special RBEEHS thermal machine (or machine of another type);
- a special electric machine (EMPM); and
- a microprocessor control system using PLC or DSP controllers.

The advantages and drawbacks of an AESS for the RBEEHS–EEHS structure are as follows:

- the AESS operation does not depend on environmental conditions, unlike, for example, is the case with wind-driven and solar-thermal facilities. It is determined by the possibilities of continuous feed of

fuel, as well as the loading requirements, which are limited by the AESS power limits;

- the AESS output power may be enhanced during use of an RBEEHS with two output shafts (Fig. 3) or during use of the principle of power extension from low-voltage cells, which are widely used in solar power supply systems (SPSs);

- application of one module of the active rectifier (AFE) working in the recuperative generator regime (Fig. 3) is promising, since the leading AFE manufacturers (AAB, Siemens, Control Techniques, et al.) for electric engines working in conditions of frequent startup, braking, and energy recuperation, are proposing solutions for them, beginning as a rule with a power at least 7 kW;

- when an RBEEHS with two shafts is needed, it is possible to arrange the AESS with a starter and generator separately;

- the cost of the AESS at the stage of elaboration and creation of the production prototype is rather high (no less than 500 thousand rubles for the power range from 3 to 10 kW) because of the high cost of RBEEHS and EMPM engines; and

- the practical RBEEHS engine resource will be determined in the process of the development test.

To model the processes and experimental studies of AESSs on based on the RBEEHSs of the PPI, an experimental test bench has been created [7], the structural diagram of which is presented in Fig. 4.

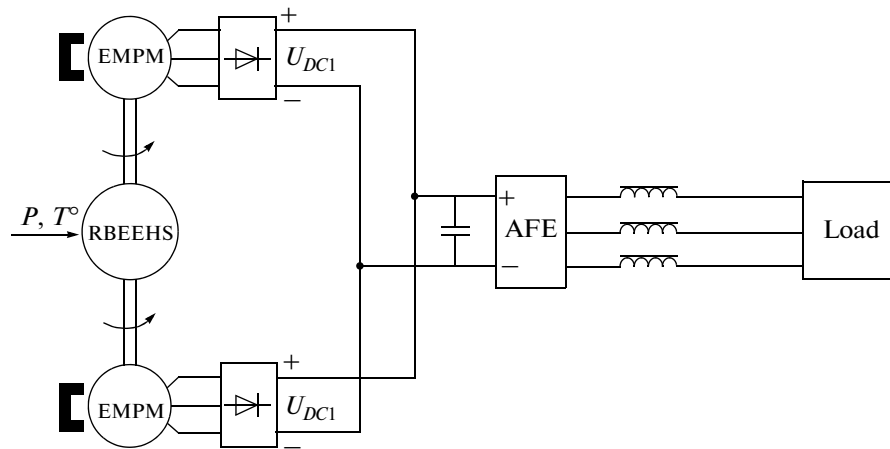


Fig. 3. Application of the AFE module working in the recuperative generator regime.

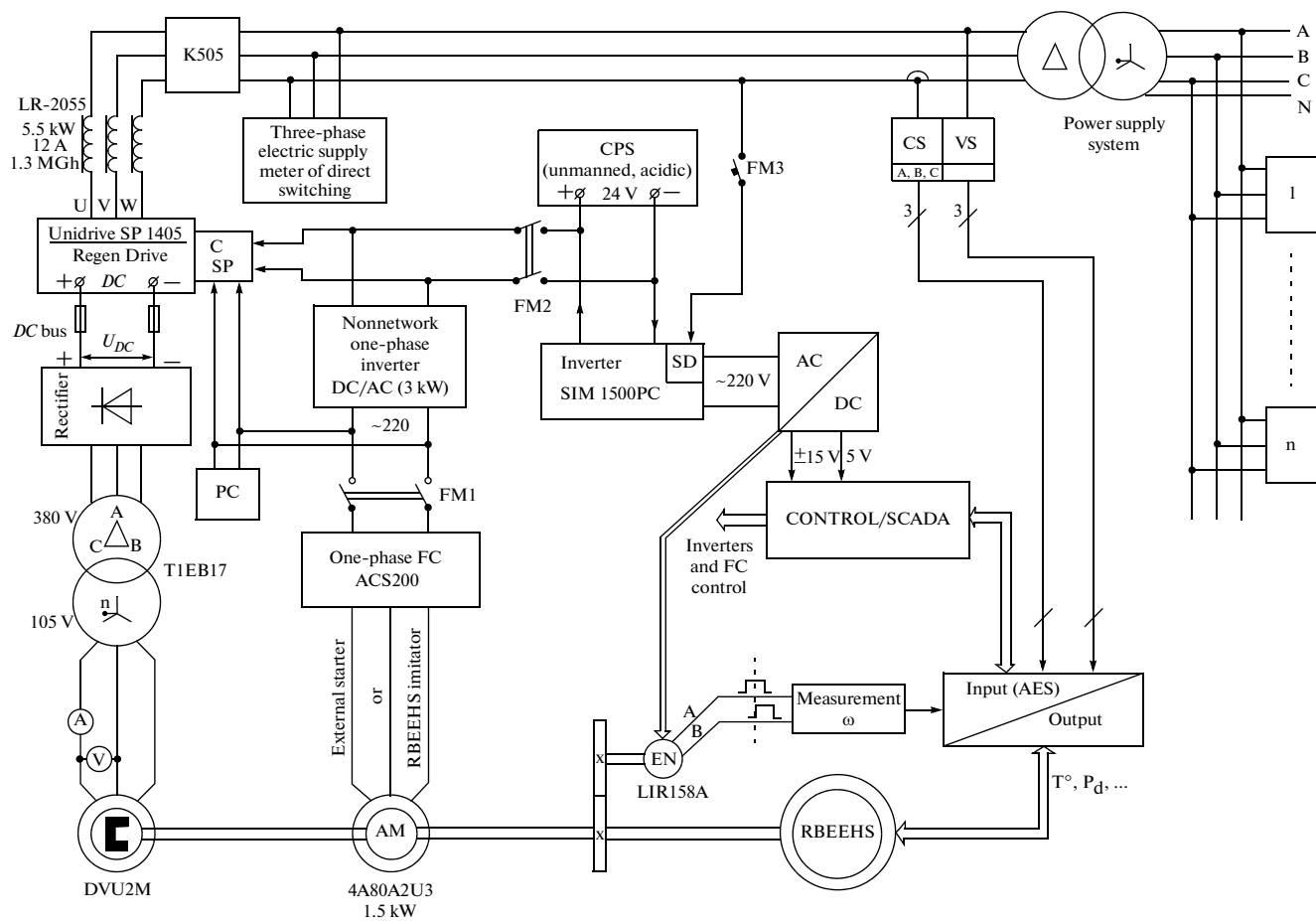


Fig. 4. Structural diagram of the experimental test bench.

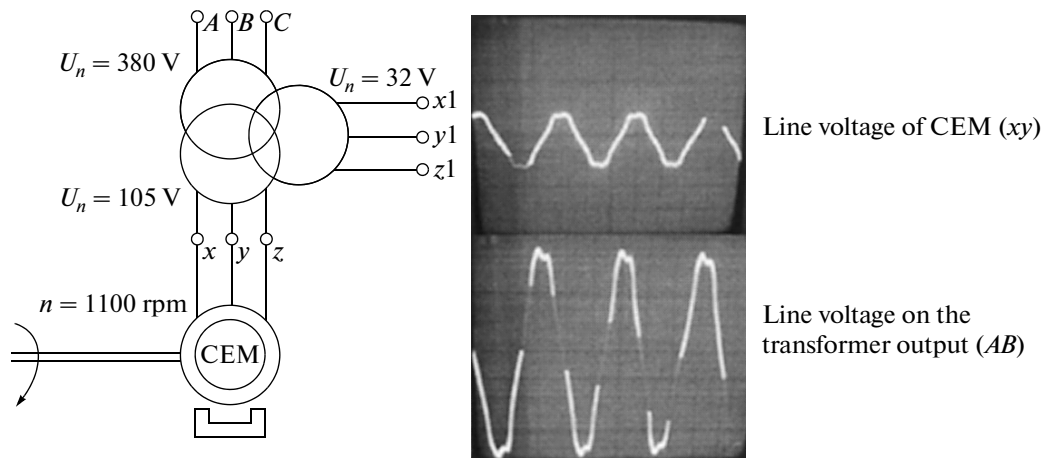


Fig. 5. Oscilloscope patterns of linear voltages of DVU type EMPM.

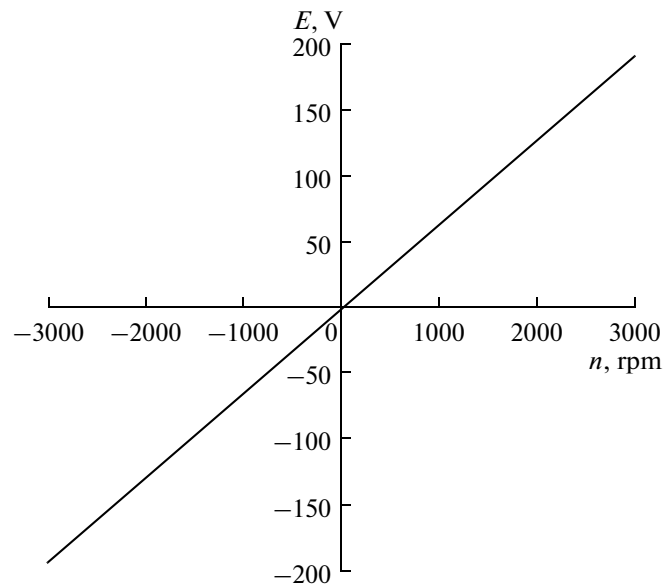


Fig. 6.

Figure 5 shows oscilloscope patterns of linear voltages of an EMPM of DVU type obtained on this bench.

The basic parameters of a general industrial EMPM of DVU2M165S type are as follows:

Maximal rotation frequency, rpm	2000
Nominal torque, N m	7
Nominal phase current, A	4.5
Maximal phase current, A	19
Rotor moment of inertia, kgm ²	0.0043
Torque constant, N m/A	1.56
Phase resistance, Ω	2.15
Inductance of two phases, H	42
Engine mass, kg	21
Permanent magnet type	Strontium ferrites

Figure 6 shows the experimental dependence of the A-phase EMF of an EMPM on the shaft's rotation frequency in the generator operation regime (for the B and C phases, the graphs are analogous). The dependence obtained is close to linear, and the average calculated transfer ratio value regarding the EMF amounts to 0.6 V/(rad/s). The expected range of output phase voltages on the stator's winding of DVU2M1658 type is 30–100 V in the range of rotation frequencies of the RBEEHS mechanical shaft.

CONCLUSIONS

(1) Power installations with Stirling engines or its RBEEHS modification are promising for use in AESSs for enhancement of the efficiency of using fuel–energy resources in the country. Manufacture of

an AEES on the basis of such installations requires application of electric generators. The use of synchronous generators with excitation by permanent magnets is promising.

(2) The work specificity of an RBEEHS in an AEES may require the use of a starter device. The starter–generator device for power installations based on an RBEEHS may be built on the basis of a general-industrial EMPM (for example, DVU2M or 5DVM) with use of domestic and foreign recuperative blocks (AFEs).

(3) Realization of a starter–generator device for an RBEEHS is possible with the use of a specialized EMPM having two three-phase stator's windings—starter and generator ones—with a shift of like phases by 30°. Manufacture of such an electric machine and analysis of the possible range of produced powers require additional electromagnetic calculations and modeling with the use of modern ELCUT and ANSYS software.

REFERENCES

1. Sibikin, Yu.D., *Netraditsionnye i vozobnovlyemye istochniki energii* (Nontraditional and Renewable Power Sources), Moscow: KNORUS, 2010.
2. Gerodes, G.A., *Vozobnovlyemye istochniki energii v Germanii* (Renewable Power Sources in Germany), Moscow: INEI RAN, 2009.
3. Kirillov, N.G., Stirling Gas Piston Engines Are the Technological Breakthrough in Independent Power Engineering in XXI Century, *GAZinform*, 2008, no. 2, pp. 34–41.
4. Plokhov, I.V., Donchenko, M.A., and Luk'yanov, Yu.N., Efficient Independent Power Plant of New Generation, in *Doklad na mezhdunarodnoi konferentsii "Innovatsionnye tekhnologii 2009"* (Proc. Int. Conf. "Innovation Technologies 2009"), Moscow: Innotekhekspo, 2009.
5. Kostyrev, M.L. and Grachev, P.Yu., *Asinkhronnye ventil'nye generatory i starter–generatory dlya avtonomnykh energoustanovok* (Asynchronous AC Converter–Fed Generators and Starter–Generators for Independent Electric Plants), Moscow: Energoatomizdat, 2010.
6. Zakharenko, A.B., New Wind Generator, *Elektrichestvo*, 2004, no. 10, pp. 65–67.
7. Khitrov, A.I., Fedotov, I.M., and Khitrov, A.A., Experimental Test Facility for Researching the Operating Conditions of Induction and AC Converter–Fed Motors for Modern Electric Drives, *Izv. TulGu*, 2010, part 4, pp. 247–253.